EE359 – Lecture 15 Outline

- **Announcements:** HW due Friday
- MIMO Channel Decomposition
- MIMO Channel Capacity
- MIMO Beamforming
- Diversity/Multiplexing Tradeoffs
- MIMO Receiver Design

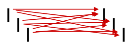
Review of Last Lecture

- Practical constraints in adaptive modulation
  - Constellation update rate

$$\bar{\tau}_j = \frac{\pi_j}{N_{j+1}+N_j} > T >> T_M$$

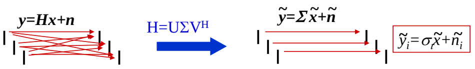
For typical Dopplers, constant for 10s to 100s of symbol times

  - Estimation error and delay
    - Lead to irreducible error floor that depends on estimation error, channel, and their joint distribution
- Introduction to MIMO Channels



MIMO Decomposition

- Decompose channel through transmit precoding ($x=V\tilde{x}$) and receiver shaping ($\tilde{y}=U^H y$)



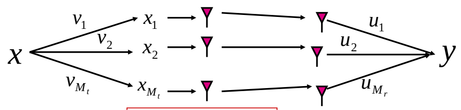
- Leads to $R_H \le \min(M_t,M_r)$ independent channels with gain σ_i (i[th] singular value of H) and AWGN
- Independent channels lead to simple capacity analysis and modulation/demodulation design

Capacity of MIMO Systems

- Depends on what is known at TX and RX and if channel is static or fading
- For static channel with perfect CSI at TX and RX, power water-filling over space is optimal:
  - In fading waterfill over space (based on short-term power constraint) or space-time (long-term constraint)
- Without transmitter channel knowledge, capacity metric is based on an outage probability
  - P_{out} is the probability that the channel capacity given the channel realization is below the transmission rate.

Beamforming

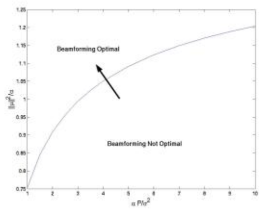
- Scalar codes with transmit precoding



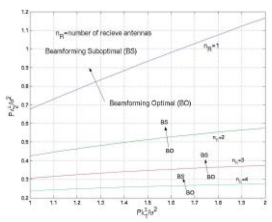
$y=u^H H v x + u^H n$

- Transforms system into a SISO system with diversity.
  - Array and diversity gain
  - Greatly simplifies encoding and decoding.
  - Channel indicates the best direction to beamform
  - Need "sufficient" knowledge for optimality of beamforming

Optimality of Beamforming



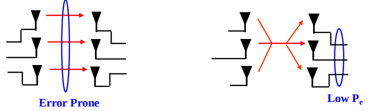
Mean Information



Covariance Information

Diversity vs. Multiplexing

- Use antennas for multiplexing or diversity

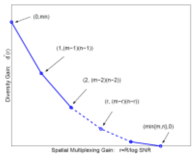


- Diversity/Multiplexing tradeoffs (Zheng/Tse)

$$\lim_{SNR\to\infty} \frac{\log P_e(SNR)}{\log SNR} = -d$$

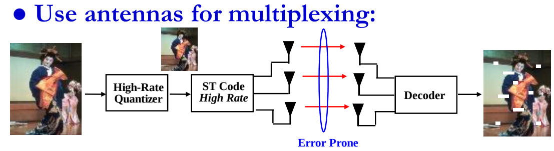
$$\lim_{SNR\to\infty} \frac{R(SNR)}{\log SNR} = r$$

$$d^*(r) = (M_t - r)(M_r - r)$$

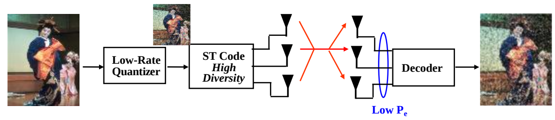


How should antennas be used?

- Use antennas for multiplexing:



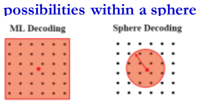
- Use antennas for diversity



Depends on end-to-end metric: *Solve by optimizing app. metric*

MIMO Receiver Design

- Optimal Receiver:
  - Maximum likelihood: finds input symbol most likely to have resulted in received vector
  - Exponentially complex # of streams and constellation size
- Decision-Feedback receiver
  - Uses triangular decomposition of channel matrix
  - Allows sequential detection of symbol at each received antenna, subtracting out previously detected symbols
- Sphere Decoder:
  - Only considers possibilities within a sphere of received symbol.



- Space-Time Processing: Encode/decode over time & space

Main Points

- MIMO systems exploit multiple antennas at both TX and RX for capacity and/or diversity gain
- With TX and RX channel knowledge, channel decomposes into independent channels
  - Linear capacity increase with number of TX/RX antennas
  - Without TX CSI, capacity vs. outage is the capacity metric
- MIMO introduces diversity/multiplexing tradeoff
  - Optimal use of antennas depends on application
- MIMO RX design trades complexity for performance